A new Solar Technology Technique for Wastewater and Seawater Treatment

Dr. Omar El-Hadad

Siti Nuda Shafinie Binti Abdul Aziz

Faculty of Chemical and Natural Resources Engineering

University Malaysia Pahang

Paper presented to the conference Water Asia 2014

Abstract

With the increasing water shortage in different parts of South-East Asia, like Singapore, and some parts of Indonesia and recently in Selangor, the need arises for more advanced technologies to treat wastewater to a level of purity where is can be used as potable. In this paper some improvements to an already available technique (the solar still) are introduced, in order to increase its productivity and make it more suitable to be used industrially, for large scale wastewater treatment projects. Problems facing the solar still are mainly related to the very low evaporation rate which is caused by the low effect of solar evaporation. Here we see a new idea to solve this problem, and introduce a low-cost application to treat wastewater, by trying to redesign the whole process under different parameters. Improvements introduced in this paper can also be used for seawater desalination.

Introduction

For a few decades already, research has shown that the world is going to face a water crisis [1]. It is known that 97.5% of the earth water is salt water from the ocean. Only 2.5% of the earth water is fresh water and of that amount, approximately 70% is frozen in ice caps, glaciers and permanent snow. That leaves just 0.3% of world water in fresh ground water [2]. This small amount of available water has to be used in industry, agriculture, and human consumption. The agricultural sector consumes about 70% of earth's fresh water [3].

Solar stills have been used for water treatment for a long period of time [4].In 1952, an American magazine mentioned that the US air force developed a solar still to aid pilots whose planes are shot down by managed to reach sea lavel [5]. However, although the technique seems simple and easy, it has not been used industrially, or to produce desalted water in large amounts. There is a patent in Pakistan [6] about the use of solar still in water desalination with large enough production of desalted water (40 L/m^3/day).

With all knowledge and advances within the seawater desalination techniques, there is still an area for a lot of improvement. Currently, most seawater desalination in the world takes place either through distillation (with conventional heating techniques) [7] or with membrane separation, with reverse osmosis as the mostly used desalination technique with seawater [8]. This is the case even in countries like Saudi Arabia, where seawater is easily accessible, solar energy is available for most of the year, but not a lot of advancement has been made to improve the quality of water desalination techniques there through the use of solar energy and solar stills.

Solar stills are mainly distillation equipment, where the water is heated with the accumulation of heat thanks to the Infrared (IR) radiation from the sun. As the temperature increases inside, the water starts to evaporate then condense on the glass wall of the solar still, similar to the water cycle in nature.

Looking particularly at South East Asia, it is easy to notice a water crisis might be on its way, with increasing water shortage problems [9]. This is having a strong impact on development economics in this region, and its massive impact may threaten the livelihood of many people in the region [10].

Techniques available for water and seawater treatment

The technique most commonly used in water treatment is rapid gravity filtration [11]. Filtration and decantation is the technique commonly used whenever there is fresh water available from a fresh resource, most likely a river or a fresh water lake. However, because of the amount of pollutants already available in the water, like small living organisms, and many pharmaceuticals which cannot be removed only through simple filtration and decantation, nanofiltration (NF) and ultrafiltration (UF) are finding more extensive use nowadays [12]. For seawater treatment, Reverse Osmosis is still the most commonly used practice, in addition to Multi-Stage Flash distillation (MSF).

MSF costs are very high, this is mainly because the technology depends mainly on boiling the water then condensing it. With the known very high sensible heat and latent heat of vaporization of water, the cost of fuel required to evaporate all this amount of water is significantly high. Even with new technologies to improve MSF efficiency [13], the cost is only reduced to a small extent.

Currently, costs of seawater desalination are too high. This is logical because of the nature of the techniques used.

When looking at seawater desalination techniques, they can be easily divided into two techniques, mainly distillation based and membrane based. Membrane based techniques mainly include Reverse Osmosis (RO), but other technologies such as Micro Filtration (MF), NF, UF. In one separation process there may be more than one membrane technique used together. For example, MF and UF are used as pretreatment for seawater before it is treated with RO [14]. Cost of seawater treatment membranes is also considered high.

What makes the process more costly is that, because of the nature of RO membranes, very high pressures must be used to push the water through the membrane. This problem is not faced for example with brackish water treatment, as the concentration of salts is usually lower than that of seawater, so the membranes do not require such a high pressure to push the water through. In case of seawater desalination, pressures required for the treatment may reach around 70 bars, which means cost increase on two sides:

1. The pumps required to provide such a high pressure are costly. Add to this that all parts of the pump in contact with sea water have to be corrosion resistant. Sea water is known to be highly corrosive. This is an addition to the capital cost required for the membrane themselves
2. The power required to run such pumps is not low. The pumps working to pressurize the water to such head have a high running cost. These pumps require a lot of power to reach this head. Consequently, the running cost will also be high.

The information stated above explain, in a summarized way, the reason why the costs of seawater desalination are high. With such high costs, for a very important material like water, there should be a way to come up with a new technology which can be used for the water treatment.

There are two other techniques available for wastewater and seawater treatment, one is sewage treatment, which is commonly used either aerobically or anaerobically. The other is biochemical effluent treatment. Although each of these two techniques has its own uses, the final product of both processes may not be directly suitable for human consumption. Further treatment through oxidation or membrane treatment might be further required.

Problems of available techniques

In all techniques mentioned above, the technique that can reduce the water to its purest level is MSF, simply because by evaporating the water, any solid wastes or living organisms will be automatically separated and left within the pond or container where untreated water is placed. None of the other techniques mentioned above can fully purify water. Membrane techniques (RO, MF, NF and UF) do not get the water to full purity. Same applies to filtration.

However, MSF has a problem related to its running cost, which is that its fuel consumption is too high. However, this paper introduces a new way for the seawater/wastewater treatment, which also depends on distillation, but uses solar energy instead of fossil fuel.

Seawater desalination using solar still is certainly a cheap and less costly technique to use. On one hand, the use of solar energy for the distillation represents a much way which is less costly to run the desalination process. One technique is already available, where the membranes are used to remove the salt from the water, but instead of powering the pumps with electricity from the grid, electricity is generated from solar cells. From the running costs perspective, this technique is certainly less costly than using the power from the grid or from diesel generators for example. However, its main problem is that there is a significant increase in the capital cost of the desalination system, as the cost of solar cells, and their additional accessories, is still high compared to the running cost for the power from the grid.

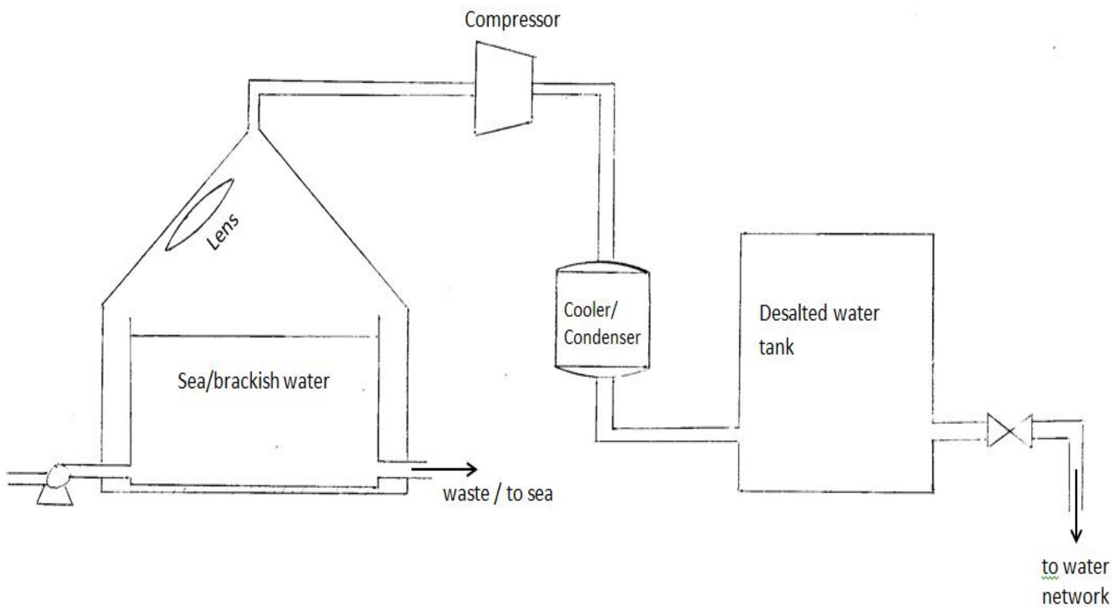

Figure 1. A schematic diagram for the suggested solar desalination technique.

The suggested technique is an addition to the already established solar still technique. As mentioned above, the solar still technique is currently being used, but usually in small scale production of water. It can produce amounts which are enough only to cover the needs of a small area, but cannot be used industrially or to cover the need of large communities.

The suggested technique runs the process as follows:

1. Seawater is fed to the tank. The tank is placed in a transparent housing, to allow the light to enter and increase the temperature with IR rays.
2. The sunlight is focused with a lens, or a number of lenses. The increased temperature inside will make the evaporation of seawater easier.
3. To decrease the difficulty of the evaporation process, a compressor is used to withdraw the air from the housing and compress it. The air taken will be saturated

with water vapor, at relative humidity 100%. Once the air is compressed, vapor drops will start to form on the walls of the pipes carrying the compressor output.

4. The steam and water are passed through a cooler/condenser. As the process is run with an excess of seawater available, the vapor will be condensed in copper pipes submerged within a seawater tank. Copper offers high thermal conductivity, and has higher resistance to the corrosion caused by the salts in the seawater.
5. The water, now mostly condensed, will pass by the water within the distilled water tank. Air which still contains small amounts of water vapor will be passed within the water, where any water vapor still in the gas phase is expected to be condensed.

Technical Problems within the Suggested Technique

There is a number of problems within the suggested technique. These problems can be summarized as follows:

1. **Glass brittleness and pressure accumulation within the distillation chamber**
   This is one of the problems which are highly likely to face the technique, especially at its first stages, or after the compressor is shut down and is turned on again. In this case, the situation within the chamber will require the accumulation of some pressure, so that there is enough steam within the air leaving the chamber.
   The cause of this problem is mainly because of the brittleness of glass. Glass is known to be very brittle, and so it cannot be used with high pressure difference between the inside and the outside of the chamber.
   This problem can be solved by using another material of construction for the chamber walls. A more suitable material could be Aluminium Oxynitride or bullet-proof glass, however both materials are quite expensive, compared to the price of normal transparent glass.
2. **Increase of boiling point with the increased pressure**
   It is known in thermodynamics that the boiling point of any liquid increases with pressure. This problem is quite related to the situation mentioned in point 1. above, but it can be solved through good control of the pressure within the chamber. Once pressure reached a specific point, the compressor can start automatically, withdrawing all the increased pressure from within the chamber. This also highlights the need that the chamber should be tightly closed, so that no vapor or gas entry can happen except through the compressor.

3. **Scaling and salt/impurities disposition**

   Scaling, or salt disposition, is another well-known problem in almost all solar desalination techniques. In RO systems for example, there must be some backwash to remove the accumulation of salts from the membranes.

   In the current system, the system simplicity offers a simple solution. In case enough water can evaporate, the seawater entry/exit can be run as a continuous process. This implies that the seawater should be left for enough time within the system to reach the required temperature and start to evaporate.

   On the other hand, if the water must be kept within the chamber until it reaches the required temperature, salt or impurities disposition can take place. This still does not represent a problem, as the seawater can be equipped with an internal plastic layer in which all the salt disposition takes place. Once it reached a specific concentration, this plastic layer is discarded with all the salt in it, a new plastic layer is placed and the tank can be filled with a new batch of seawater. This second solution is more suitable for seawater in areas containing calcium salts which have decreased solubility with increasing temperature.

4. **Focus control**

   With the continuous movement of the sun, it is very difficult to control the movement of the lens or mirror focus. The problem is further magnified as water is transparent, so even if the focus could be controlled somehow, it will be still difficult to use it as a heating medium in itself. Our experiments using a magnifying glass focus (10 cm diameter) show that the temperature at the focus could be as high as 75 ^{o}C. At this saturation temperature, a pressure below 0.4 bar can cause water to boil. On an industrial scale unit, using a bigger lens could lead to a temperature above 1000 ^{o}C. However, focusing the light at a specific transparent point still remains as a problem.

5. **Cooler/condenser design**

   The design of the cooler/condenser is simple. Using seawater as a cooling medium, the steam coming to the condenser must be condensed inside the tubes of the condenser, while seawater is stirred outside for the cooling process to take place at a higher efficiency. However, the piping material remains as a problem for the cooler/condenser.

   First suggestion was to use pure copper pipes, however, a lab experiment done by placing a copper bar in a beaker filled with seawater for one week has ended after the seawater colour turned blue, showing that copper in its pure or commercially available alloys is not corrosion resistant for seawater.

Another option is to use a copper alloy, as suggested in the literature [15]. However, using a copper/nickel alloy for example will reduce the thermal conductivity of copper from 400 W/mK (for pure copper) to a range of 25-50 W/mK (for different seawater compatible cupronickel alloys) [16]. This is a very low thermal conductivity compared to that of pure copper.

Another option is to make the pipes of carbon nanotubes. Carbon nanotubes have very high thermal conductivity, up to about 6000 W/mK [17]. However, carbon nanotubes are very expensive, so trying to use them in a large scale process might increase the cost significantly.

Impact of this technique on Water Supply

Establishing this model and designing this equipment will ensure a more robust water safety policy and easier accessible potable water supply for Malaysia. Malaysia is already starting to face a water shortage problem [18], which places water safety as a government priority especially in Sarawak [19].

Conclusion

A new technique for seawater/wastewater treatment has been suggested here. Although there are still many questions not answered yet, answering such questions will enable the production of the first solar energy industrial scale seawater/wastewater treatment unit. Thermodynamic/heat transfer calculations show that it is possible to produce such a unit, and the ongoing experiments show the high possibility for potential success for this idea and project.

References

[1] Shiklomanov, I. , Water. In P. H. Gleick, *Water in Crisis: A Guide to World's Fresh Water Resources* Oxford University Press, USA, **1993**

[2] Ehlers, E. K., *Understanding the Earth System: compartment, Processes and Interaction* Springer, **2001**

[3] Clay, J.; *World Agriculture and the Environment: A Commodity-by-Commodity Guide to Impacts and Practices* Island Press, **2004**
[4] Tiwari, G and Tiwari, A., Solar Distillation Practice For Water Desalination Systems, Anshan Ltd., UK, **2008**
[5] Engel L., *Miniature Revolution*, in *Popular Mechanics*, February **1952**.
[6] Zuberi, A., Pakistan Patent No. on 133598, sighted in http://en.wikipedia.org/wiki/Solar_desalination
[7]Ettouney, H., Ahmad, R., *Operational Experiences of Desalination Processes in the Middle Eastern countries*, American Water Works Association Membrane Technology Conference, **2003**.
[8] Lauer, W., *Desalination of Seawater and Brackish water*, American Water Works Association, **2006**.
[9] Laborte, A. G.; de Bie, K.; Smaling, E. M. A.; Moya, P. F.; Boling, A. A.; Van Ittersum, M. K.; *Rice yields and yield gaps in Southeast Asia: Past trends and future outlook*, European Journal of Agronomy, 36, 1, 9-12, **January 2012.**
[10] Xu J. C. And Thomas D.; *Climate Change in the Montane Mainland Southeast Asia: Reflections on water resources and livelihoods*, in Sajise P. E.; Ticsay M. V. And Saguihuit G. C.; *Moving Forward, Southeast Asian Perspectives on Climate Change and Biodiversity*, ISEAS Publishing, Singapore, **2010**.
[11] Ahmad, R. *Filtration Water Treatment*, Water Encyclopedia, Wiley Online Library **2005**.
[12] Sadmani, A. H. M.; Andrews R.; Bagley, D; *Nanofiltration of pharmaceutically active and endocrine disrupting compounds as a function of compound interactions with DOM fractions and cations in natural water*, Separation and Purufication Technology, 122, 462–471, **2014**
[13] Al-Weshahi M. A.; Anderson A.; Tian G.; *Exergy efficiency enhancement of MSF desalination by heat recovery from hot distillate water stages*, Applied Thermal Engineering, 53,2, 2, 226–233, **2013**
[14] Henthorne, L.; Jankel, E; Quigley, R; *Pilot Testing of MF and UF for Seawater RO Pretreatment*, **2003** AWWA Membrane Technology Conference.
[15]Schweitzer, Fundamentals of Metallic Corrosion. CRC Press, Taylor and Francis Group. **2007**
[16] http://www.copper.org/ , the Copper Development Association website

[17] Han, Z and Fina, A; Thermal conductivity of carbon nanotubes and their polymer nanocomposites: A review, Elsevier Progress in Polymer Science, 36, 7, 914–944, July **2011**
[18] News easily obtained from different Malaysian newspapers, like the star, March 22, **2011** or New Straits times, June 16 **2012**.
[19] Sarwak Government Offical Portal, http://www.sarawak.gov.my/en/media-centre/in-the-news/view/sarawak-plays-host-to-international-water-safety-conference-and-borneo-water-and-wastewater-exhibition, November **2010**